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A COMPARISON OF SALT REQUIREMENTS FOR YOUNG AND FOR MATURE BUCKWHEAT PLANTS IN WATER CULTURES AND SAND CULTURES

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In recent experimental work[1] bearing on the growth of plants in nutrient solutions, it has been demonstrated that the three salts, mono-potassium phosphate, calcium nitrate, and magnesium sulphate, in the proper proportions, in solutions of suitable concentrations, furnish a medium very well adapted to general culture work. This three-salt solution produces excellent growth and has the additional advantage of being the simplest nutrient solution (with respect to the number of salts employed) which can be devised and still contain all the elements, except iron, essential for plant growth. To determine approximately the optimum salt proportions for wheat (*Triticum vulgare*) during the first four weeks after germination, and for buckwheat (*Fagopyrum esculentum* Moench) during the early period of growth from germination to flowering, an optimal series of 36 different solutions was employed. All the solutions had approximately the same total osmotic concentration value of 1.75 atmospheres, and the salts were so distributed as to include all possible sets of salt proportions; when the partial concentrations of the three components were made to vary by increments equal to one tenth of the total concentration. Each solution contained the usual trace of iron as ferric phosphate, in addition to the three salts. Tests of the 36 different proportions of the nutrient salts showed that the best growth of wheat tops was produced by a solution containing the three salts in the following volume-molecular proportions: $KH_2\ PO_4$, 0.0180 m.; $Ca(NO_3)_2$, 0.0052 m.; and $MgSO_4$, 0.0150 m. The best growth of buckwheat tops and of roots was obtained in a solution in which the partial volume-molecular concentrations of the three salts were: KH_2PO_4, 0.0144 m.; $Ca(NO_3)_2$, 0.0052 m.; and $MgSO_4$, 0.0200 m.

These proportions of the three salts are, of course, to be considered approximately optimum only for wheat and buckwheat during the first four weeks of their growth after germination. It seemed highly desirable to determine whether the salt proportions required for optimum growth during the later periods of development, for the maturing of the plants, and for seed production, are the same or different from those above given for approximately optimum growth of seedlings. An attempt was made in this direction, and it is the purpose of the present paper to state the main results of the work in a preliminary way. The tests were carried out with buckwheat, first in water cultures. Similar tests were then made with sand cultures.

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[1] Shive, J. W. A three-salt nutrient solution for plants. Amer. Journ. Bot. 4: 157–160. 1915.

The methods employed with water cultures were the same as those previously employed by Shive[2] in his work with wheat. The seeds were germinated and the seedlings were mounted (three seedlings to each culture) in the manner described in the publication just cited (pp. 343–344), and were then placed in the culture vessels, which consisted of pint "Mason" jars. Each culture vessel contained 515 cc. of the same solution. This solution had the salt proportions, above given, which produced the highest yield of buckwheat tops during the first four weeks of growth after germination. All the seedlings were grown in this solution (with renewal of solutions every five or six days) during the first 24-day period. At the end of this time the plants were nearly alike. Some of the plants of each culture were in bloom and all the plants appeared healthy and vigorous. At the end of this early growth period the cultures were transferred to the 36 different solutions of the optimal three-salt series, each with a total osmotic concentration value of 1.75 atmospheres. These included all the possible sets of salt proportions for increments of change equal to one tenth of the total osmotic concentration. One culture was also transferred to Knop's solution and one to Tottingham's[3] best solution for wheat, each with a total concentration equal to that of the three-salt solutions. The cultures were now continued, with renewal of solutions as before, until the seeds were mature. This required a time period of 28 days. The first series was conducted from October 21 to December 9. This was repeated between December 9 and January 20.

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[2] Shive, J. W. A study of physiological balance in nutrient media. Physiol. Res. 1: 327–397. 1915.

[3] Tottingham, W. E. A quantitative chemical and physiological study of nutrient solutions for plant cultures. Physiol. Res. 1: 133–345. 1914.

The solution giving the best growth of buckwheat tops contained the three salts in the following volume-molecular partial concentrations: $KH_2 PO_4$, 0.0108 m.; $Ca(NO_3)_2$, 0.0130 m.; and $MgSO_4$, 0.0100 m. This solution also produced the highest yield of roots. It will be observed that these proportions are not at all the same as are those which produced the maximum yield of buckwheat tops and of roots during the early period of growth, from germination to flowering. It thus appears that the salt proportions of the best physiologically balanced solutions for buckwheat during the early period of growth are totally different from those which characterize the best physiological balance for these plants during the later period, from flowering to maturity.

The optimal series of solutions with a total osmotic concentration value of 1.75 atmospheres was repeated in sand cultures, with renewal of solutions as in the tests with solution cultures. The renewal of solutions in sand cultures was accomplished by a method similar to that employed by McCall.[4] The containers, consisting of earthenware pots glazed inside and outside, each held 2,500 g. of washed, air-dry, white quartz sand. The sand in each pot was flooded with an initial application of 750 cc. of solution, the excess of which was then withdrawn, leaving the sand with a moisture content of approximately 15 percent of the weight of the air-dry sand. The excess solution was withdrawn through a glass tube extending to the bottom of the pot, instead of through a metal tube sealed to the bottom of the pot, as was done by McCall. This method was found entirely satisfactory and prevented the possibility of any metal coming in contact with the solution.

The first series of sand cultures was continued, with renewal of solutions (250 cc. of solution with each renewal) every three or four days, until the plants were in bloom. This required a time period of 25 days after the seedlings were transferred to the sand cultures. The series was then repeated. These two series of sand cultures, one conducted in May and the other in June, corresponded to the two series of solution cultures conducted during the early period of growth, from germination to flowering.

The solution in sand culture giving the highest yield of buckwheat tops during this early period of growth contained the three salts in the same volume-molecular partial concentrations as did the solution giving the highest dry weight of tops and of roots in the corresponding series of water cultures. In the solution of the sand culture which gave the highest dry weight of roots[5] the volume-molecular partial concentrations were not the same as were those in the solution giving the highest dry weight of tops. The volume-molecular proportions of the three salts which gave the highest yield of roots were: KH_2PO_4, 0.0180 m.; $Ca(NO_3)_2$, 0.0104 m.; $MgSO_4$, 0.0050 m.

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[4] McCall, A. G. A new method for the study of plant nutrients in sand cultures. Amer. Soc. Agron. 7: 249–252. 1915.

To determine the salt proportions required to produce approximately optimum growth of buckwheat in sand cultures during the period between flowering and maturity, the following procedure was adopted: The plants were first grown to the flowering stage in sand cultures, all of which contained the same solution. This solution had the salt proportions giving the best growth of tops in sand culture and in water culture during the early period of growth, from germination to flowering. The solutions were renewed every three or four days. At the end of this early 25-day period the cultures were all nearly alike, the plants throughout showing exceptional uniformity.

The solutions in the sand cultures were now replaced by the 36 different solutions of the optimal three-salt series. This was accomplished by passing through the sand of each culture (after first adding sufficient distilled water to bring the entire system back to its original weight) a triple portion (750 cc.) of the new solution, thus flushing out the old solution and replacing it with the new. At the same time the solution of one culture was replaced with Knop's solution, and that of another with Tottingham's best solution for wheat, each with a total osmotic concentration value of 1.75 atmospheres.

The series was now conducted, with renewal of solutions as before, until the seeds were mature. This second growth period extended over a time interval of 30 days. The series was then repeated. The first of these two series was conducted from April 25 to June 19. The second series, which was just like the first, was carried out between July 2 and August 27.

The highest yield of tops, of roots, and of seeds, was obtained from the same culture. The solution of this culture contained the three salts in the same volume-molecular partial concentrations as did the solution of the corresponding series of water cultures which produced the highest dry weights of tops and of roots. These volume-molecular partial concentrations are: KH_2PO_4, 0.0108 m.; $Ca(NO_3)_2$, 0.0130 m.; and $MgSO_4$, 0.0100 m. This set of salt proportions is not at all the same as that which produced the highest yields of tops or of roots in sand cultures during the early growth period, from germination to flowering.

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[5] The dry weights of roots from the sand cultures were obtained by a method similar to that employed by McCall, Physiological balance of nutrient solutions for plants in sand cultures. Soil Science 2: 207–253. 1916.

The results here presented are brought together in the following table which gives also the dry weight yields of tops, roots, and seeds, expressed in terms of the corresponding yields from Knop's solution and from Tottingham's best solution for wheat tops, taken as unity. Each of these data represents the averages from two corresponding series.

Relative Dry Weights, and Salt Proportions Producing Maximum Yields of Buckwheat with an Optimal Series of Three-salt Solutions, in Water Cultures and in Sand Cultures, during Two Different Physiological Growth Periods

			Volume-molecular Partial Concentrations			Yields of Tops, Roots, Seeds, Relative to Those from	
			KH_2PO_4	$Ca(NO_3)_2$	$MgSO_4$	Knop's Solution taken as 1.00	Tottingham's Solution taken as 1.00
Buckwheat grown to flowering (early growth period)	Water cultures	Tops	0.0144	0.0052	0.0200	1.61	1.33
		Roots	0.0144	0.0052	0.0200	1.58	1.27
	Sand cultures	Tops	0.0144	0.0052	0.0200	1.38	1.25
		Roots	0.0180	0.0104	0.0050	1.47	1.16
Buckwheat grown to maturity (late growth period)	Water cultures	Tops	0.0108	0.0130	0.0100	1.40	1.35
		Roots	0.0108	0.0130	0.0100	1.50	1.39
		Seeds	0.0108	0.0078	0.0200	1.28	1.74
	Sand cultures	Tops	0.0108	0.0130	0.0100	1.40	1.26
		Roots	0.0108	0.0130	0.0100	1.27	1.26
		Seeds	0.0108	0.0130	0.0100	1.24	1.17

From these results it is at once clear that the salt proportions required to produce the best physiological balance for buckwheat during the two different growth periods here considered differ markedly and in the same manner with water cultures and with sand cultures. It appears that the best physiological balance of salt proportions for buckwheat with this optimal three-salt series of solutions is not greatly disturbed when these solutions, with frequent renewals, are employed in sand cultures. This is clearly shown by the fact that the salt proportions producing maximum yields of tops in water cultures are in perfect agreement with those giving the highest dry weights of tops in the corresponding series of sand cultures, during each of the two different growth periods. This is further emphasized by a similar agreement between the salt proportions producing maximum yields of roots in the series of water cultures and in the corresponding series of sand cultures, during the late growth period, from flowering to maturity, although there is no such agreement between the salt proportions producing the maximum yield of roots in water culture and those giving the highest dry weight of roots in sand culture, during the early growth period. The salt proportions which produced the highest yield of seeds in water culture are not like those which gave the highest dry weight in sand culture. In this connection it should be mentioned, however, that the water cultures were conducted at a season of the year when insects were absent, and pollination by artificial means was perhaps imperfectly accomplished. The plants of the sand cultures, on the other hand, were in bloom at a time when insects were abundant, and these had free access to the plants. It will be observed that in this series the salt proportions giving the best growth of tops and of roots are the same as those which produced the highest yield of seeds.

It is interesting to observe that with three out of the four average series here represented, there is a definite correlation between the growth of tops and that of roots, as is clearly indicated by the perfect agreement between the salt proportions producing the highest dry weight of tops and those giving the maximum yields of roots.

As the relative dry weight values in the last two columns of the above table indicate, the three-salt mixture with a total osmotic concentration value of 1.75 atmospheres, and with proper salt proportions, produced markedly higher yields than did either Knop's or Tottingham's solution with the same total osmotic concentration, for the two different physiological growth periods here considered.

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